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# Investigation of User Effects on Mobile Phased Antenna Array from 5 to 6 GHz

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***Abstract*—The goal of this paper is to evaluate the impact of the user to the performance of a phased antenna array in the frequency range from 5 to 6 GHz. The design consists of four quarter wavelength dipoles printed on the short edge of an *FR4* substrate. Simulations including a 105° phase shifter proved that the antenna array can cover a 120° beamwidth, with a gain of 7 dBi. The analysis of the user effects in terms of total scan pattern (TSP) and coverage efficiency is carried out via simulations both in data mode and in talk mode. The comparison with the performance in free space shows a loss in gain from 2 dB up to 7 dB, due to the user hand and the user hand-head respectively. Simulation results have been confirmed by the measurements of the prototype with a hand and head phantoms.**

***Index Terms*—Mobile terminal antenna, phased array, 6 GHz, 5 GHz, User effects, coverage efficiency.**

## I. Introduction

The fifth generation mobile communication system *(5G)* has been shown exponential growth in data rate requirements. One of the key enabling techniques in 5G systems is the use of millimeter-wave (*mm*-wave) and centimeter-wave (*cm*-wave) technology, which guarantees Gigabit-per-second data rate [1]–[4]. Along with the use of *mm/cm*-wave frequencies, also the sub-6 GHz bands typical of *4G* systems have been considered; hence, the demand of antennas able to cover both the new frequencies and to be tightly integrated with the existing 4G bands.

However, the use of *mm/cm*-wave spectrum will put challenging requirements on the design of antennas for the new generation mobile phones. In fact, in *mm/cm*-wave bands, free-space path loss is much higher than in conventional cellular bands below 6 GHz [5], [6], if we assume antenna gain is fixed. Moreover, coverage issues have to be faced. Hence, beamforming appeared to be the right solution to overcome the path loss at the high frequencies, as described in [2] and [7] and directional phased-array antennas, typical of 4G mobile phones [8], [9], have been considered to be applied at both the mobile device and the base station [10]. Furthermore, since beam steering does not solve coverage issues, when using only one array, it is needed to place more antenna systems in different points of the device to cover a wider area.

Last but not least, user effect has to be considered, when designing antennas for the new generation mobile phones. Many research efforts [11], [12] made over the years proved and quantified the human body interaction. The effects on the total radiated power (TRP) and the radiation pattern were evaluated in [13], by using phantoms and humans, and the impact of the user hand/hands on the mobile antenna performance was studied in [14] and [15]. In [16] the absorption of the millimeter waves by humans has been studied. It is interesting to observe that a big amount of power is lost in the human hand and head and a significant change in the shape of the radiation pattern occurs. Moreover, the investigation using the coverage efficiency metric defined in [17], including user effects, has been done in [18] at 28 GHz, where 12 users have been measured in the anechoic chamber. The performance investigation of the phased arrays with user effects has been done at 3.5 GHz in [19], where four sub-arrays of two elements each have been applied. Similar studies have been conducted in [9] and [20] at 28 and 15 GHz respectively.

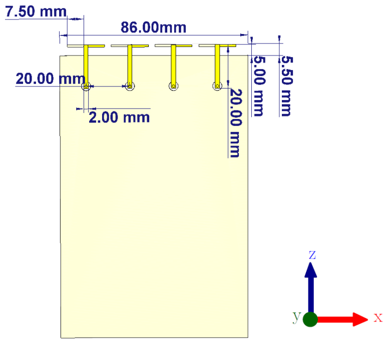
In this paper the performance of the phased antenna array, consisting of 4 array elements, has been investigated with user effect in the band from 5 to 6 GHz. The free space, data and talk modes have been considered for the simulations in CST Microwave Studio. Furthermore, the measurements have been conducted in the Satimo Starlab [21] located in a shielded anechoic chamber at Aalborg University. The setup including the right hand phantom for the data mode and the right hand next to head phantom for the talk mode are in accordance with the CTIA test plan [22]. To evaluate the performance of the antenna system in the three different scenarios, the total scan pattern (TSP) and coverage efficiency have been calculated in the band of interest and mean coverage efficiency has been extracted from the results. Finally, the three setups have been compared to each other.

The paper is organized as follows. The design of the proposed phased antenna array is presented in Section I. Section II deals with the performance of the system in free-space, expressed in terms of TSP and coverage efficiency, both for the simulations and for the measurements. Section III shows the analysis of the user effects in data and talk mode, followed by a comparison with the results in free-space. Finally, Section IV concludes the paper.

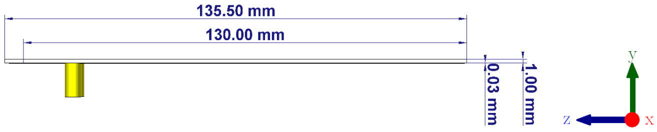
## II. Phased Antenna Array Geometry

The design of the antenna array is shown in Fig. 1. Four quarter wavelength dipoles, spaced 20 mm from each other, are printed on both sides of a FR4 substrate. In particular, half dipole, placed in the bottom of the structure, is grounded in the antenna ground plane and half dipole on top is connected to a microstrip line fed by an *SMA* connector.

The simulations run over the structure prove that, using a 70° or 150° phase shifter, the antenna system allows to steer a beam of 90° and 120° respectively with a maximum gain of 7 dBi in both cases.




(a)

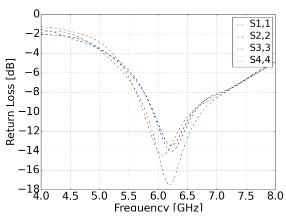



(b)

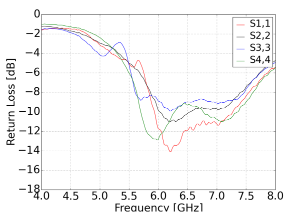
Fig. 1. Design of the prototype in (a) the xz-plane and (b) the zy-plane.

## III. Free Space Performance

As reported in Fig. 2(a), the working frequency of each of the dipoles is in the interval from 6 to 6.5 GHz and the −10 dB bandwidth is approximately 500 MHz with a maximum of 1 GHz for the fourth element. The prototype, realyzed in the laboratory of the Antennas, Propagation and Millimeter-Wave Systems (APMS) section at Aalborg University, is presented in Fig. 3, where the waveguide ports have been replaced by SMA connectors. Comparing the plots in Fig. 2, it results that the reflection coefficients of the structure, measured with the *Keysight N5227A PNA*, are in accordance with the simulations.




(a)




(b)

Fig. 2. Reflection coefficients in free space of (a) simulated array and (b) measured array.

Next, to evaluate the spatial coverage performance of the proposed phased antenna array system the TSP and coverage efficiency metrics have been applied. The TSP of a phased antenna array is obtained from all array patterns corresponding to the beam for the different array scan angles by extracting the best achievable gain value at every angular distribution point. The spatial performance of the phased antenna array can be described in terms of the coverage efficiency. Coverage efficiency is defined as [17]:

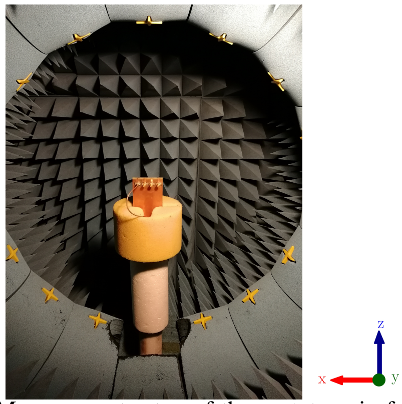



Fig. 3. Measurement setup of the prototype in free space.

$$\eta_c = \frac{\text{Coverage Solid Angle}}{\text{Maximum Solid Angle}} \tag{1}$$

where maximum solid angle is defined as $4\pi$ steradians in order to account for the arbitrary angle of arrival and arbitrary orientation of the mobile device. The coverage efficiency is calculated from the total scan pattern with respect to the chosen set of the gain values. In this work it has been chosen to use gain values ranging from -15 to 10 dBi.

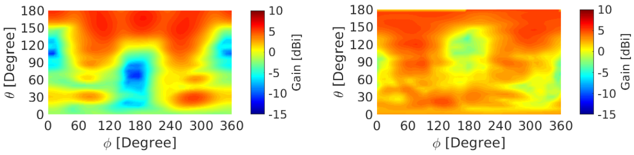
The Satimo measuring equipment consists of a ring with 15 bi-directional and dual polarized test probes, a base-station emulator, *CMW500*, and a computer receiving the measured data from the device under test. The first step was the calibration of the anechoic chamber, followed by the evaluation of the *E*-field of each dipole separately over the 3D full sphere. The rotation of the setup, positioned in the center of the ring, allowed to measure each point on the $\phi$-axis, while the probe array carried out the measurement of each point over the $\theta$-axis.

The *E*-field values, gathered for each of the four antennas, have been processed in *MATLAB* and the resulting TSP is shown in Fig. 4(b), in comparison with the one of the simulated structure (Fig. 4(a)). The evaluated values of TSP for the antenna array were reported in a *2D*-plot, where the color bar indicates an increasing gain from -15 to 10 dBi. The TSP of the measured prototype looks like the one obtained from the simulations, but in the first case the gain is higher in correspondence of lower values of $\theta$, vice versa in the second case.

Moreover, in Fig. 5 the coverage efficiency from 5 to 6 GHz is plotted versus the realized gain. Choosing $\eta_c = 0.5$, the gain of the measured structure is 3 dB higher than the one of the simulated, as it can clearly result from the comparison of the curves representing the mean efficiency calculated over 21 frequency points.

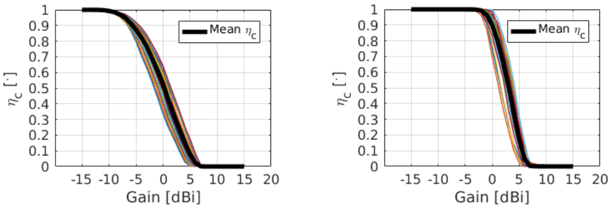
## IV. User Effects

To evaluate the influence of the user on the performance of the antenna array, the device has been simulated and measured with a phantom hand in data mode and the phantom hand




(a) (b)

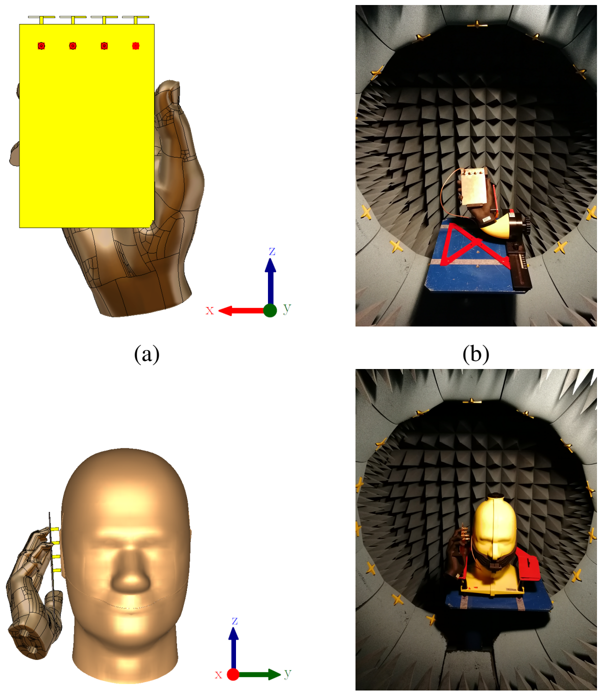
Fig. 4. Total scan pattern in free space at 5.5 GHz of (a) simulated array and (b) measured array.




(a) (b)

Fig. 5. Coverage efficiency in free space from 5 to 6 GHz with a step of 50 MHz of (a) simulated array and (b) measured array.

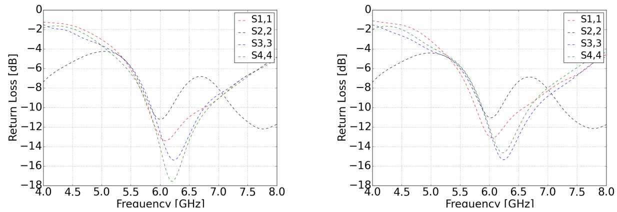
next to a phantom head in talk mode. The setup simulated in CST can be seen in Figs. 6(a) and 6(c). The simulated hand and head phantoms represent the prototypes used for the measurements which are in accordance with the CTIA specifications and are produced by Speag. In Fig. 6(b) and Fig. 6(d) the setup for the measurements in the Satimo Starlab has been shown.



(a) (b) (c) (d)

Fig. 6. Measurement setup of the prototype for (a) data mode – simulated array, (b) data mode – measured array, (c) talk mode – simulated array, and (d) talk mode – measured array.

Looking first at the simulated reflection coefficients in Fig. 7 and comparing them with the ones in Fig. 2(a), it is possible to notice that only the curve of $S_{2,2}$ is affected by the user. In fact, the the second dipole is the only one touched by the middle finger of the hand phantom.



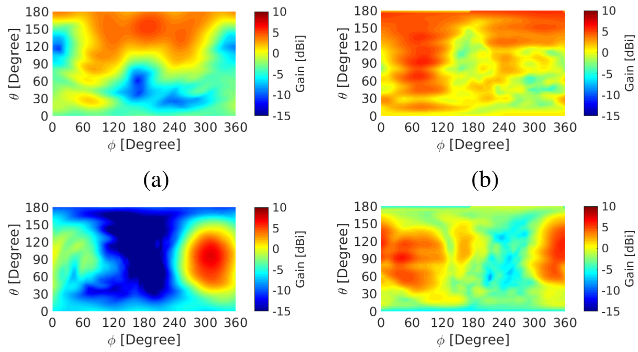

(a) (b)

Fig. 7. Reflection coefficients of the simulated array for (a) data mode and (b) talk mode.

The impact of the user has been measured in terms of TSP and coverage efficiency and the results of the simulations and the measurements for both data and talk mode are reported in Figs. 8 and 9. Comparing the simulated TSP including the user effects with the one in free space (Fig. 4), it is clear to notice that the hand phantom does not highly impact the radiation pattern of the antenna array, meaning that the user hand produces a negligible absorption.

On the other hand, the presence of the head phantom significantly decreases the gain of the device in talk mode, which is visibly lower than −5 dBi in most of the pattern. The same comments apply to the measured TSP and to the coverage efficiency, plotted in Fig. 9. In fact, fixed $\eta_c = 0.5$, it is possible to notice a reduction of the gain of 5 dB in the simulations including the head phantom, compared to the performance in free space.

Finally, the plot in Fig. 10 shows that the loss due to the hand phantom is 2 dB at $\eta_c = 0.5$, whereas the head phantom increases the loss up to 7 dB. Better values of the coverage efficiency have been gathered by the measurements. Comparing the curves, it is also possible to notice that, fixed any value of $\eta_c$, the loss due to the user effect is much lower compared to the simulations.




(a) (b) (c) (d)

Fig. 8. Total scan pattern at 5.5 GHz of (a) data mode – simulated array, (b) data mode – measured array, (c) talk mode – simulated array, and (d) talk mode – measured array.

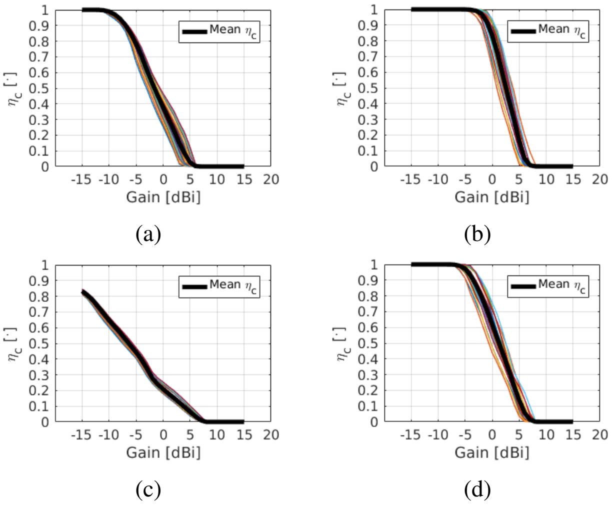



Fig. 9. Coverage efficiency from 5 to 6 GHz with a step of 50 MHz of (a) data mode – simulated array, (b) data mode – measured array, (c) talk mode – simulated array, and (d) talk mode – measured array.

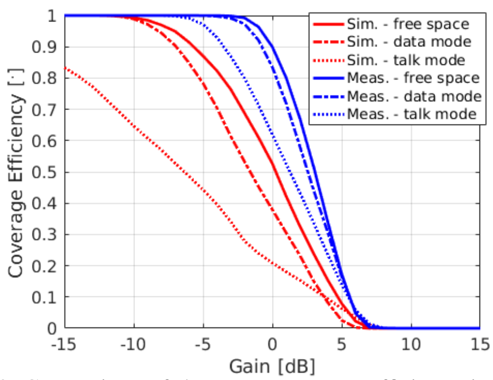



Fig. 10. Comparison of the mean coverage efficiency in the band.

## V. Conclusion

This work focused on the investigation of the user effect on the performance of a phased antenna array, evaluated in terms of total scan pattern and coverage efficiency.

To accomplish this goal, the proposed phased antenna array was simulated using CST and then measured in a Satimo Starlab in three different setups: free space, data mode and talk mode. The results were compared by considering the metrics of total scan pattern and mean coverage efficiency, averaged over 21 frequency points in frequency range from 5 to 6 GHz. As expected, both the simulations and the measurements led to the similar conclusions, the influence of the hand phantom was negligible compared to the effect of the head phantom. This has been explained by the position of the user hand, which does not affects the radiation direction of the dipoles. In fact, for a fixed value of the coverage efficiency ($\eta_c = 0.5$), the gain decreases 2 dB in comparison to the free space. On the other hand, the absorption and shadowing in talk mode are more significant, due to the proximity of the user's head. For the fixed coverage efficiency value of $\eta_c$ the loss of 7 dB has been observed.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